CLAIMS

1. A method for conveying digital data from a transmitter to a receiver, comprising:

specifying a spectral filtering profile to be applied in conveying the data;

generating a sequence of input symbols at the transmitter corresponding to the data to be conveyed;

precoding the input symbols at the transmitter using Tomlinson-Harashima precoding responsive to the specified profile, so as to generate a corresponding sequence of precoded symbols;

filtering the precoded symbols in accordance with the specified profile; and

decoding the precoded and filtered symbols at the receiver so as to recover the data therefrom.

2. A method according to claim 1, wherein specifying the spectral filtering profile comprises specifying a notch filter to be applied to the precoded symbols.

3. A method according to claim 2, wherein filtering the precoded symbols comprises attenuating radio-frequency signals transmitted by the transmitter in a predetermined frequency band, so as to avoid generating radio frequency interference in that band.

4. A method according to claim 2, wherein filtering the precoded symbols comprises attenuating radio-frequency signals received by the receiver in a predetermined frequency band, so as to reject radio frequency interference received in that band.

5. A method according to claim 1, wherein the specified profile comprises an infinite impulse response filter profile.

6. A method according to claim 1, wherein filtering the precoded symbols comprises filtering the symbols at the transmitter.

7. A method according to claim 6, wherein filtering the symbols comprises filtering the symbols based on predetermined filtering parameters, and comprising communicating the parameters from the transmitter to the receiver for use in processing the symbols at the receiver.

8. A method according to claim 1, wherein filtering the precoded symbols comprises filtering the symbols at the receiver.

9. A method according to claim 8, wherein filtering the symbols comprises filtering the symbols based on predetermined filtering parameters, and comprising communicating the parameters from the receiver to the transmitter for use in precoding the input symbols.

10. A method according to claim 1, wherein generating the sequence of input signals comprises generating the sequence with a given input constellation, and wherein filtering the precoded symbols comprises generating output symbols having an output constellation that is expanded relative to the input constellation.

11. A method according to claim 10, wherein precoding the input symbols comprises applying the Tomlinson-Harashima precoding such that each of the input

symbols can be recovered by taking a modulo of a corresponding one of the output symbols.

12. A method according to claim 11, wherein generating the sequence of input symbols comprises generating symbols having real and imaginary parts, and wherein precoding the input symbols comprises precoding both the real and imaginary parts of the input symbols such that both the real and imaginary parts can be recovered by taking a two-dimensional modulo of the real and imaginary parts of the corresponding output symbols.

13. A method according to claim 12, wherein generating the sequence of input symbols comprises generating Quadrature Amplitude Modulation (QAM) symbols.

14. A method according to claim 1, wherein the precoded symbols are conveyed from the transmitter to the receiver over a channel having a channel response, and wherein specifying the spectral profile comprises specifying at least a portion of the profile substantially independently of the channel response.

15. A method according to claim 14, wherein filtering the precoded symbols further comprises optimizing a power spectral density of the conveyed precoded symbols responsive to the channel response.

16. A method according to claim 14, and comprising determining the channel response, wherein precoding the input symbols comprises using the Tomlinson-Harashima precoding responsive to the channel response, as well as to the specified profile.

17. A method according to claim 1, wherein precoding the input symbols comprises:

filtering the sequence of precoded symbols by applying a feedback filter response thereto, so as to generate a corresponding sequence of feedback symbols, wherein the feedback filter response is substantially equal to the filtering profile less a zero-order time-domain component of the profile;

subtracting the feedback symbols from the corresponding input symbols, so as to generate a corresponding sequence of subtracted symbols; and

mapping the subtracted symbols to the corresponding precoded symbols, such that each of the subtracted symbols in the sequence can be recovered by taking a modulo of the corresponding precoded symbol.

18. A method according to claim 17, wherein generating the sequence of input symbols comprises generating Quadrature Amplitude Modulation (QAM) symbols, having respective real and imaginary parts, and wherein mapping the subtracted symbols comprises mapping both real and imaginary parts of the subtracted symbols.

19. A method according to claim 17, wherein specifying the spectral filtering profile comprises specifying a filter response given in the z-domain by A(z)/B(z), A and B complex polynomials, and

wherein the precoded symbols are conveyed from the transmitter to the receiver over a channel having a channel response H(z), and

wherein applying the feedback filter comprises applying a filter with a response F(z) given substantially by $F(z) = \left[\left(1 + z^{-1} \cdot DFEh(z)\right) \cdot A(z) - B(z)\right] / B(z)$,

wherein DFEh(z) is an equalizer response of a decision feedback equalizer that is suitable to compensate for the channel response at the receiver.

20. A method according to claim 19, wherein decoding the symbols comprises adaptively determining the response DFEh(z) at the receiver, and wherein applying the filter with the response F(z) comprises conveying an indication of the determined response DFEh(z) to the transmitter for application by the feedback filter.

21. A method according to claim 1, wherein the transmitter transmits Very High Rate Digital Subscriber Line (VDSL) signals to the receiver based on the sequence of precoded symbols.

22. A method according to claim 1, wherein decoding the symbols at the receiver comprises taking a modulo of each of the symbols so as to recover the corresponding input symbol.

23. A method according to claim 22, wherein the receiver receives the symbols from the transmitter over a channel having a given channel response, and wherein decoding the symbols comprises applying a digital equalizer to the symbols so as to compensate for the channel response.

24. A method according to claim 23, wherein applying the digital equalizer comprises adaptively determining equalization coefficients for application by the equalizer responsive to the channel response.

25. A method according to claim 24, and comprising conveying an indication of the adaptively-determined coefficients to the transmitter, wherein precoding the

input symbols comprises adjusting the Tomlinson-Harashima precoding responsive to the indication.

26. A method according to claim 25, wherein decoding the symbols comprises substantially deactivating the digital equalizer after adjusting the precoding.

27. A method according to claim 26, wherein determining the equalization coefficients comprises refraining from filtering the precoded symbols while determining the coefficients.

28. A method according to claim 25, wherein determining the equalization coefficients comprises determining the coefficients while filtering the precoded symbols.

29. A method according to claim 24, wherein generating the sequence of input signals comprises generating the sequence with a given input constellation, and wherein filtering the precoded symbols comprises generating output symbols having an output constellation that is expanded relative to the input constellation, and wherein adaptively determining the equalization coefficients comprises finding a distribution of the output constellation and computing the coefficients responsive to the distribution.

30. A method according to claim 23, wherein applying the digital equalizer comprises applying a forward equalizer and a digital feedback equalizer.

31. A high-speed data transmitter, comprising:

a Tomlinson-Harashima precoder, which is adapted to receive and precode a sequence of input symbols responsive to a specified spectral filtering profile, so

as to generate a corresponding sequence of precoded symbols; and

transmit circuitry, which is adapted to process the precoded symbols so as to generate an output signal for transmission over a communication channel to a receiver.

32. A transmitter according to claim 31, wherein the specified spectral filtering profile comprises a notch filter response.

33. A transmitter according to claim 32, wherein the transmit circuitry comprises a digital filter, which is adapted to filter the precoded symbols responsive to the notch filter response.

34. A transmitter according to claim 33, wherein the output signal comprises a radio-frequency signal, and wherein the digital filter is adapted to apply the notch filter response so as to attenuate the radio-frequency signal in a predetermined frequency band, so as to avoid generating radio frequency interference in that band.

35. A transmitter according to claim 31, wherein the transmit circuitry is configured to transmit the output stream over a channel having a channel response, and wherein at least a portion of the profile is specified substantially independently of the channel response.

36. A transmitter according to claim 35, wherein the precoder and transmit circuitry are further configured to optimize an output power spectral density of the transmitter responsive to the channel response.

37. A transmitter according to claim 31, wherein the transmit circuitry is configured to transmit the output signal over a channel having a given channel response,

and wherein the precoder is adapted to precode the input symbols responsive to the channel response, as well as to the specified profile.

38. A transmitter according to claim 31, wherein the precoder comprises:

a feedback digital filter, which is adapted to apply a feedback filter response, based on the specified spectral filtering profile, to the sequence of precoded symbols so as to generate a corresponding sequence of feedback symbols;

a subtractor, adapted to subtract the feedback symbols from the corresponding input symbols, so as to generate a corresponding sequence of subtracted symbols; and

a modulo mapping device, adapted to map the subtracted symbols to the corresponding precoded symbols, such that each of the subtracted symbols in the sequence can be recovered by taking a modulo of the corresponding precoded symbol.

39. A transmitter according to claim 38, wherein the symbols comprise Quadrature Amplitude Modulation (QAM) symbols, having respective real and imaginary parts, and wherein the modulo mapping device is adapted to map both the real and imaginary parts of the subtracted symbols.

40. A transmitter according to claim 38, wherein the spectral filtering profile is given in the z-domain by A(z)/B(z), A and B complex polynomials, and

wherein the channel has a channel response H(z), and

wherein the feedback filter response F(z) is given substantially by $F(z) = \left[\left(1 + z^{-1} \cdot DFEh(z)\right) \cdot A(z) - B(z)\right] / B(z)$,

wherein DFEh(z) is an equalizer response of a decision feedback equalizer that is suitable to compensate for the channel response at the receiver.

41. A transmitter according to claim 38, wherein the feedback digital filter comprises an infinite impulse response filter.

42. A transmitter according to claim 31, wherein the output signal stream comprises Very High Rate Digital Subscriber Line (VDSL) signals.

43. Apparatus for high-speed data transmission, comprising:

a transmitter, which comprises:

a Tomlinson-Harashima precoder, which is adapted to receive and precode a sequence of input symbols responsive to a specified spectral filtering profile, so as to generate a corresponding sequence of precoded symbols; and

transmit circuitry, which is adapted to process the precoded symbols so as to generate an output signal for transmission over a communication channel; and

a receiver, adapted to receive the output signal from the transmitter over the channel, and comprising:

receive circuitry, which is adapted to process the received output signal, so as to generate a stream of output samples;

a decision block, adapted to process the stream of output samples so as to recover a sequence of output symbols; and

a modulo reduction device, adapted to take a modulo of each of the recovered output symbols so as to regenerate the input symbols.

44. Apparatus according to claim 43, wherein the specified spectral filtering profile comprises a notch filter response.

45. Apparatus according to claim 43, wherein at least one of the transmit circuitry and the receive circuitry comprises a digital filter, which is adapted to apply the specified filtering profile to the signal.

46. Apparatus according to claim 45, wherein the digital filter comprises a transmit digital filter in the transmit circuitry and a receive digital filter in the receive circuitry, which are together adapted to apply the specified filtering profile.

47. Apparatus according to claim 45, wherein the digital filter comprises a transmit digital filter in the transmit circuitry, the filter having filter parameters, and wherein the transmitter is adapted to transmit the filter parameters to the receiver for use in processing the output samples.

48. Apparatus according to claim 45, wherein the digital filter comprises a receive digital filter in the receive circuitry, the filter having filter parameters, and wherein the receiver is adapted to transmit the filter parameters to the transmitter for use in precoding the input symbols.

49. Apparatus according to claim 43, wherein the communication channel has a channel response, and wherein

at least a portion of the profile is specified substantially independently of the channel response.

50. Apparatus according to claim 43, wherein the communication channel has a channel response, and wherein the precoder is adapted to precode the input symbols responsive to the channel response, as well as to the specified filtering profile.

51. Apparatus according to claim 43, wherein the output signal comprises a Very High Rate Digital Subscriber Line (VDSL) signal.

52. Apparatus according to claim 43, wherein the precoder comprises:

a feedback digital filter, which is adapted to apply a feedback filter response, based on the specified spectral filtering profile, to the sequence of precoded symbols so as to generate a corresponding sequence of feedback symbols;

a subtractor, adapted to subtract the feedback symbols from the corresponding input symbols, so as to generate a corresponding sequence of subtracted symbols; and

a modulo mapping device, adapted to map the subtracted symbols to the corresponding precoded symbols, such that each of the subtracted symbols in the sequence can be recovered by taking a modulo of the corresponding precoded symbol.

53. Apparatus according to claim 52, wherein the feedback digital filter comprises an infinite impulse response filter.

54. Apparatus according to claim 52, wherein the spectral filtering profile is given in the z-domain by A(z)/B(z), A and B complex polynomials, and

wherein the channel has a channel response H(z), and

wherein the feedback filter response F(z) is given substantially by $F(z) = \left[\left(1 + z^{-1} \cdot DFEh(z)\right) \cdot A(z) - B(z)\right] / B(z)$,

wherein DFEh(z) is an equalizer response of a decision feedback equalizer that is suitable to compensate for the channel response at the receiver.

55. Apparatus according to claim 54, wherein the decision feedback equalizer is comprised in the decision block of the receiver and is configured to adaptively determine the response DFEh(z), and wherein the receiver is adapted to convey to the transmitter an indication of the determined response DFEh(z) for application by the feedback filter.

56. Apparatus according to claim 52, wherein the decision block comprises:

a decision feedback equalizer, which is configured to apply decision feedback filtering to the recovered sequence of output symbols, so as to generate a corresponding sequence of decision feedback symbols;

a forward filter equalizer, which is configured to apply forward equalization to the stream of output samples so as to generate a sequence of forward-equalized symbols;

an adder, adapted to add the decision feedback symbols to the forward-equalized symbols to generate a corresponding sequence of corrected symbols; and

an extended slicer, adapted to assign each of the corrected symbols to a corresponding value in a constellation of the output symbols.

57. Apparatus according to claim 56, wherein the decision feedback equalizer comprises an adaptive equalizer, having equalization coefficients determined adaptively responsive to the channel response.

58. Apparatus according to claim 57, wherein the receiver is adapted to convey to the transmitter an indication of the equalization coefficients, responsive to which the feedback filter response is determined so that the precoder precodes the input symbols based on the channel response, as well as on the specified profile.

59. Apparatus according to claim 58, wherein after the indication of the equalization coefficients is conveyed to the transmitter, the decision feedback equalizer is substantially disabled.